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Academic year 2017/2018

Airglow measurements with AMON detector

"Università degli Studi di Torino "

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Traineeship in Kosice – May and June 2018

Figure 1. Institute of Experimental Physics, Slovak Academy of Science , Kosice

Figure 2. High Tatras - Lomnický štít (2634 m)

Amon project → JEM-EUSO

The Extreme Universe Space Observatory onboard Japanese Experiment Module (JEM-EUSO)

First space mission concept devoted to the investigation of cosmic rays and neutrinos of extreme energy (E > 5×10^{19} eV).

↓

UV light in atmosphere

Distinction: Sources (natural, artificial), Temporal evolution (transient, stable), Spatial distribution, Strength

Most important UV light sources:

- Auroras
- Moonlight
- Transient luminous phenomena
- Man-made sources
- Airglow

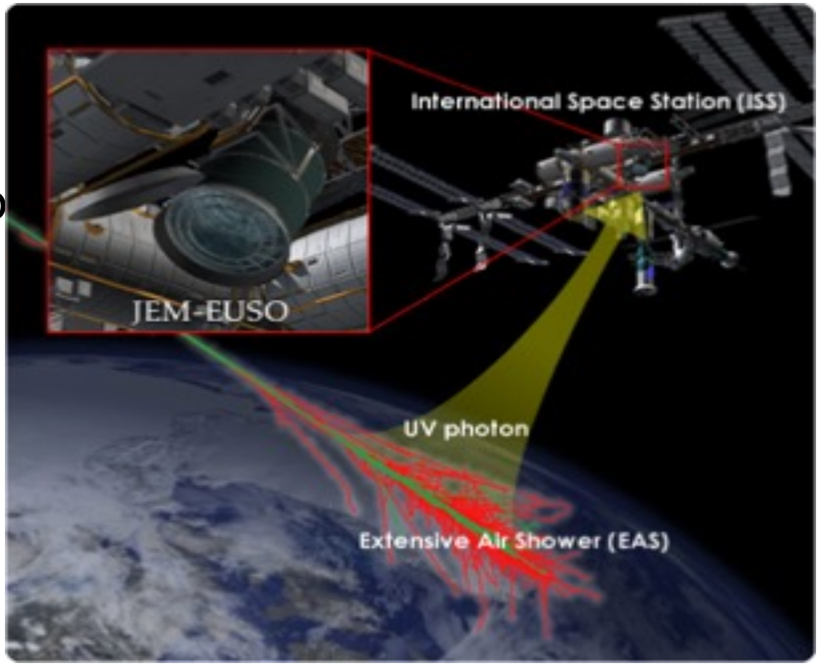


Figure 3. Jem-Euso on the international Space Station (ISS)

Airglow

- Light of electronically and/or vibration-rotationally excited atoms and molecules 80 km or higher, due to solar UV radiation.
- Contamination for fluorescence detectors.
- Seasonal, geographical and daily variations are possible.
- Essential to monitor it for the ground-based telescope and for the space-based telescope (observing EAS)

Figure 4. Airglow over the VLT platform

- **Atomic oxygen green radiation**
  - 558nm light from oxygen atoms at 90-100 km high
  - clearly visible from earth orbit

- **Atomic oxygen red light**
  - lower energy excited state at 150 - 300 km
  - collisions infrequent

- **Sodium** → yellow light from sodium atoms (layer at 92 km).

- **O2** → weak blue emissions from excited molecular oxygen (at ~95 km).

- **OH** → excited OH radicals emit red and infra-red at ~ 86-87 km

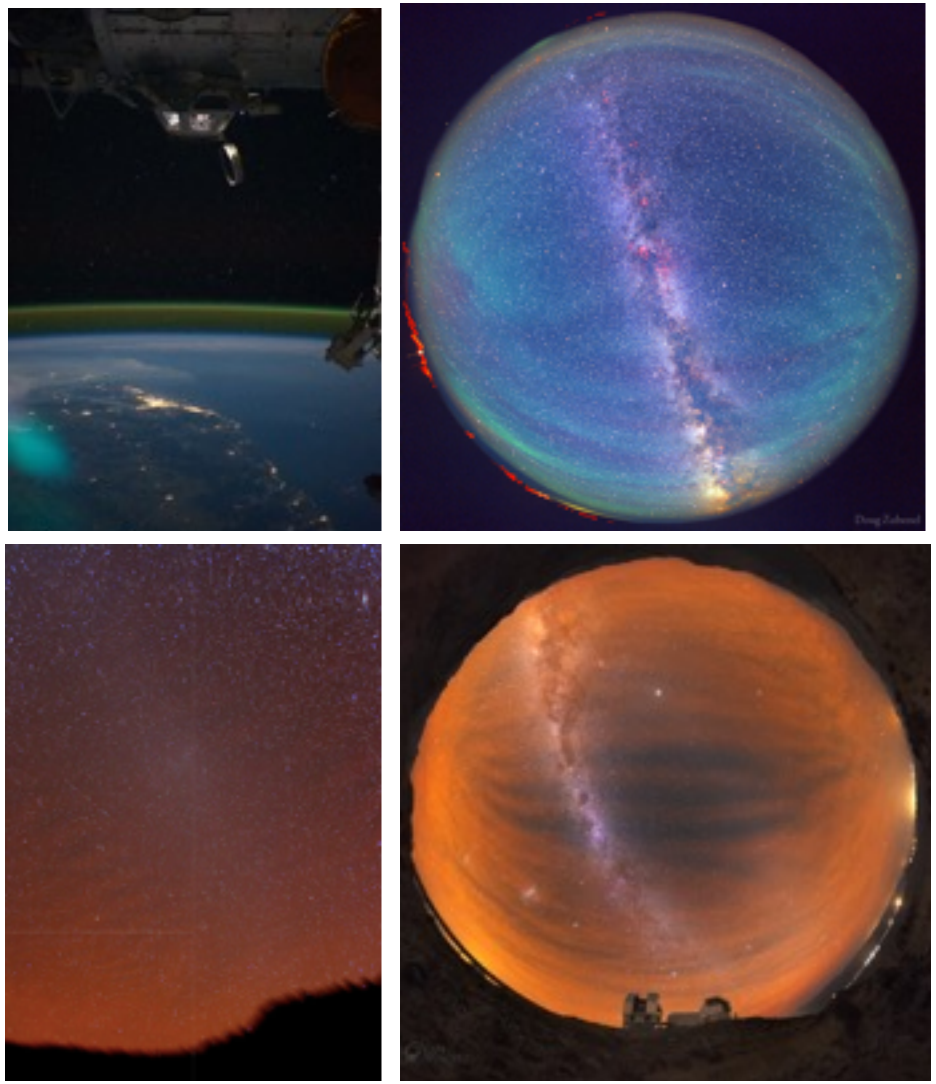
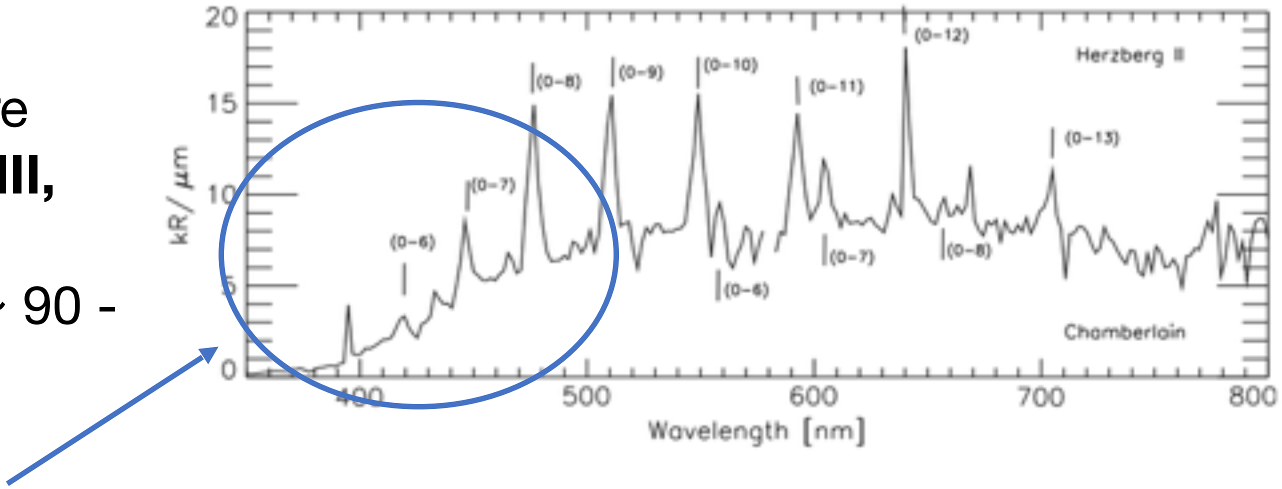


Figure 5. The airglow captured from the ISS – Banded airgloe from Nebraska Star Party in Merritt Reservoir - Banded red airglow -Milky Way vs Airglow Australis, by Yuri Beletsky in Carnegie Las Campanas Observatory

- The most intensive band systems are **Herzberg I, Herzberg II, Herzberg III, and Chamberlain system** with the maximum of production at altitude ~ 90 - 100 km a.s.l.



- The light in the range 300-500 nm is important for Cosmic Rays studies. It's generated by the following **physical process**:

During the day : $O_2 + h\nu \rightarrow O + O$

During the night: $O + O + M \rightarrow O_2^* + M$

where M represents another atom (oxygen or nitrogen) that is needed for the reaction.
The molecules in metastable state have a short lifetime :

$$O_2^* \rightarrow O_2 + h\nu$$

AMON detector

- Very sensitive photomultiplier (PMT): **Hamamatsu μPMT HI24-00-01**
- Thorlabs BG3 bandpass filter
- Narrow collimator with geometrical factor $3{,}45 \cdot 10^{-6} cm^2 sr$
- 70% of observed airglow light is in the 300-400 wavelength range
- Photons aquired in 1s period and converted in ADC counts
- Waterproof - 575 grams - 110 x 75 x 57 mm
- Thermometer, balometer, luxmeter, GPS sensor
- Standard internet connection

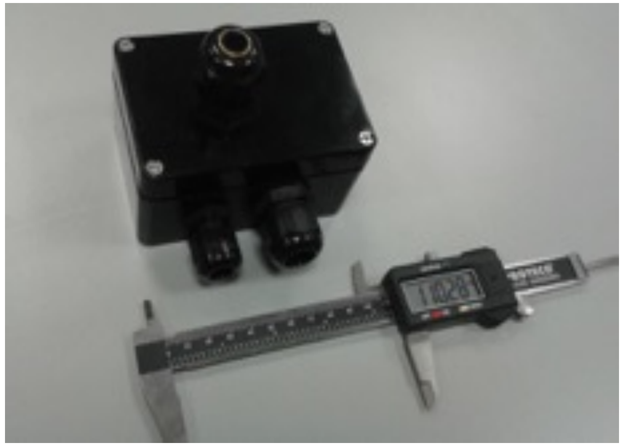


Figure 6 . AMON detector

Figure 7. Hamamatsu μPMT HI24-00-01

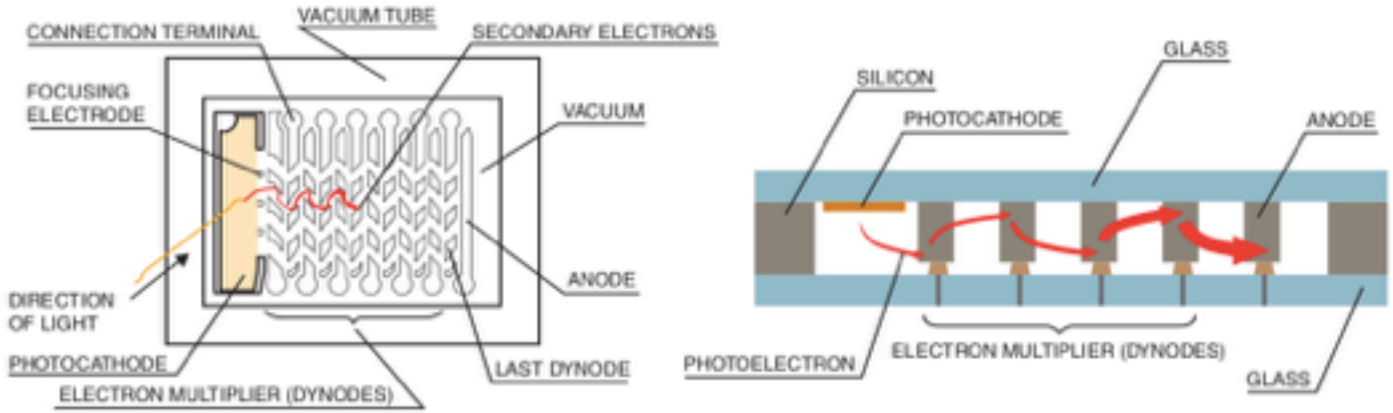
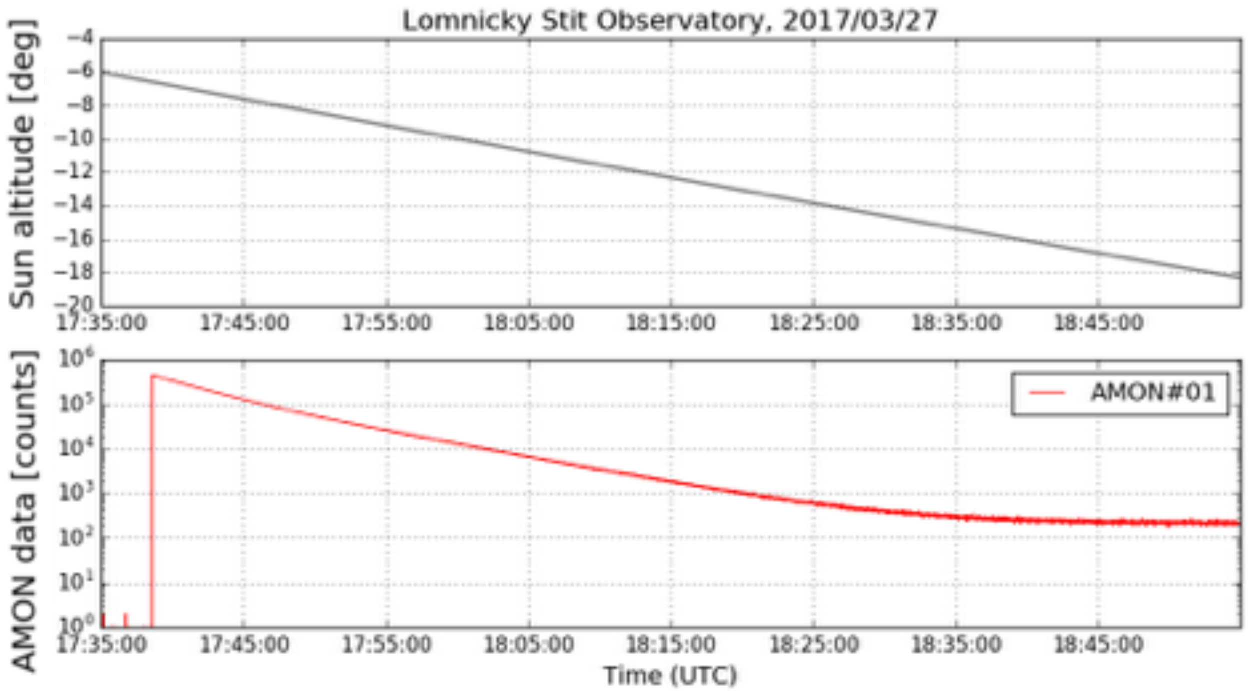


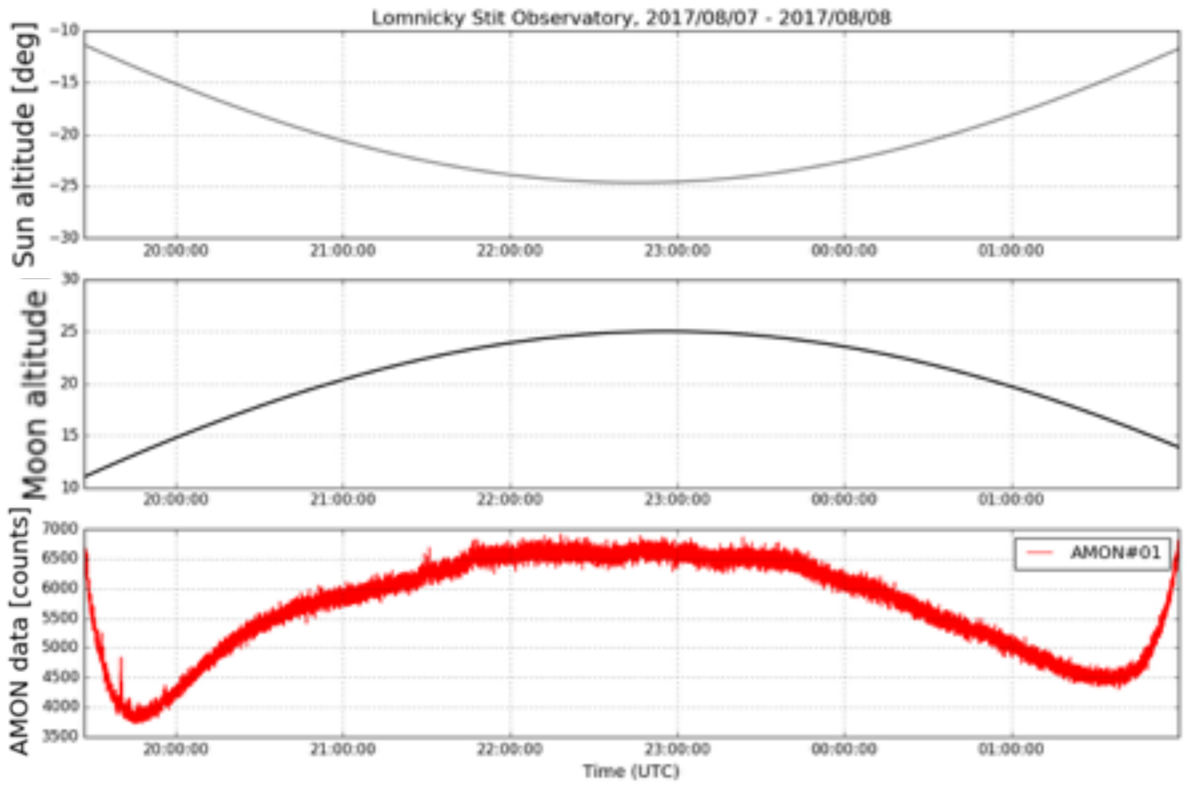
Figure 8. Hamamatsu μPMT HI24-00-01 internal structure

Selection of the suitable data for the analysis

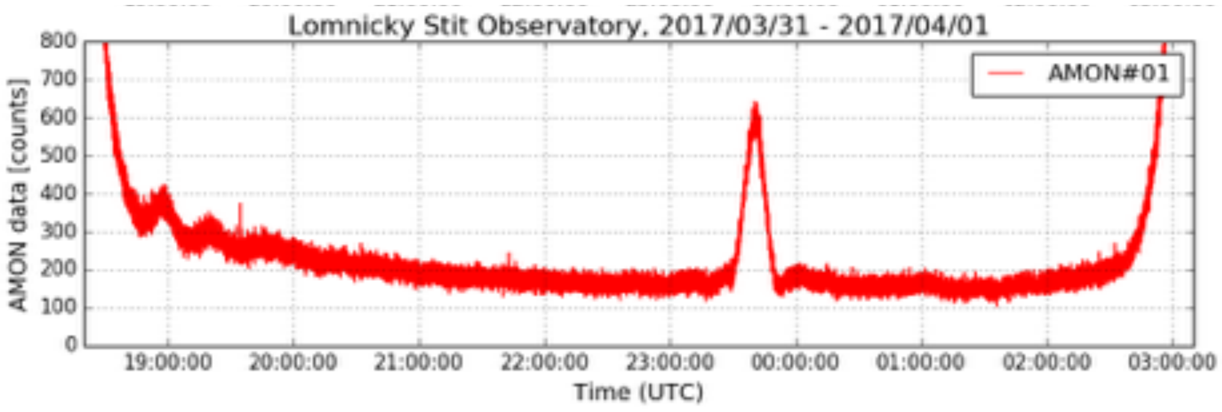
- Altitude of the Sun above the horizon



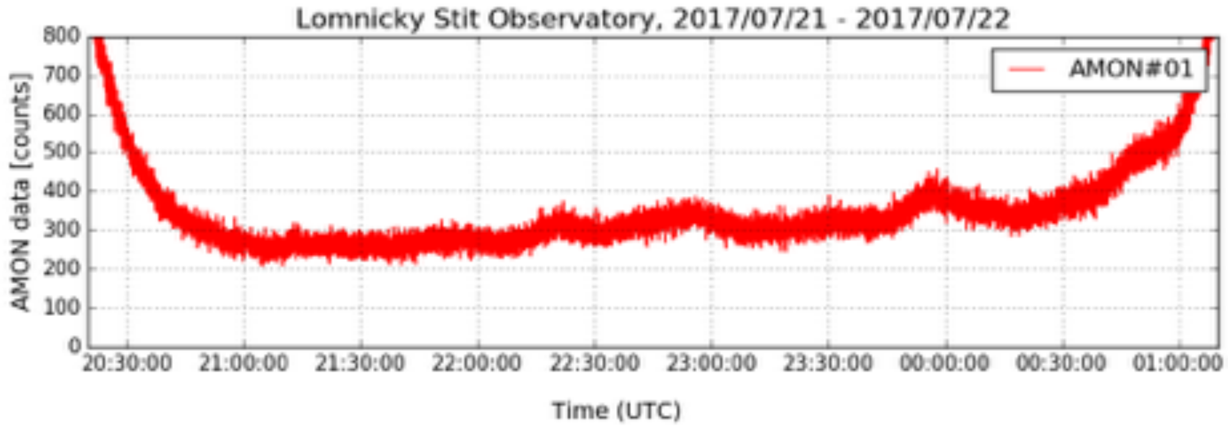
- Exclusion of the moonlight effect



- Bright astronomical objects in the FoV

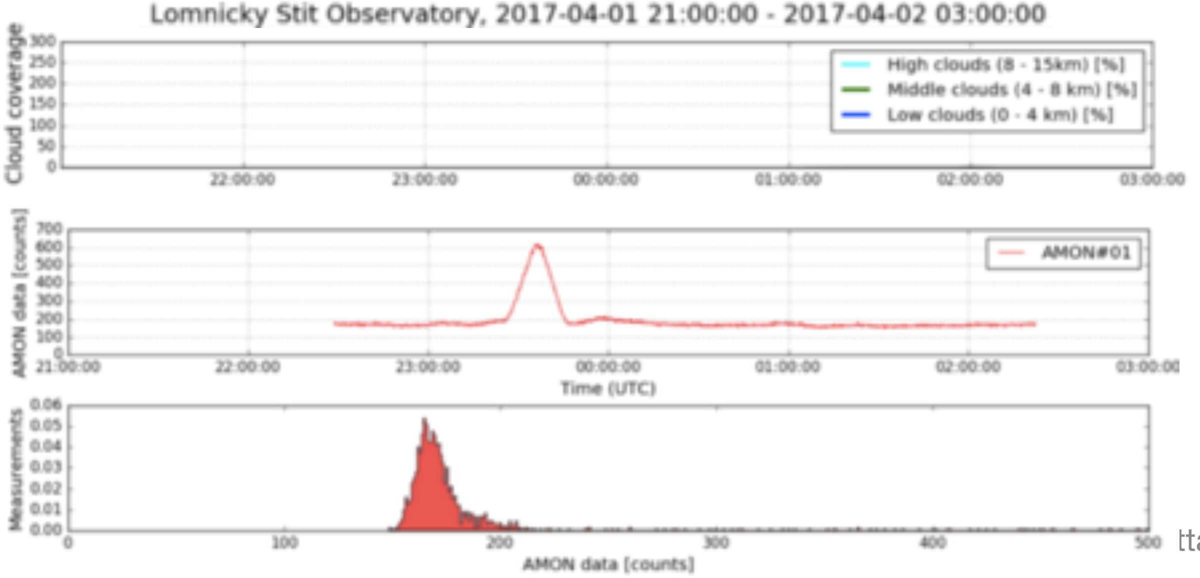


- Presence of Milky Way

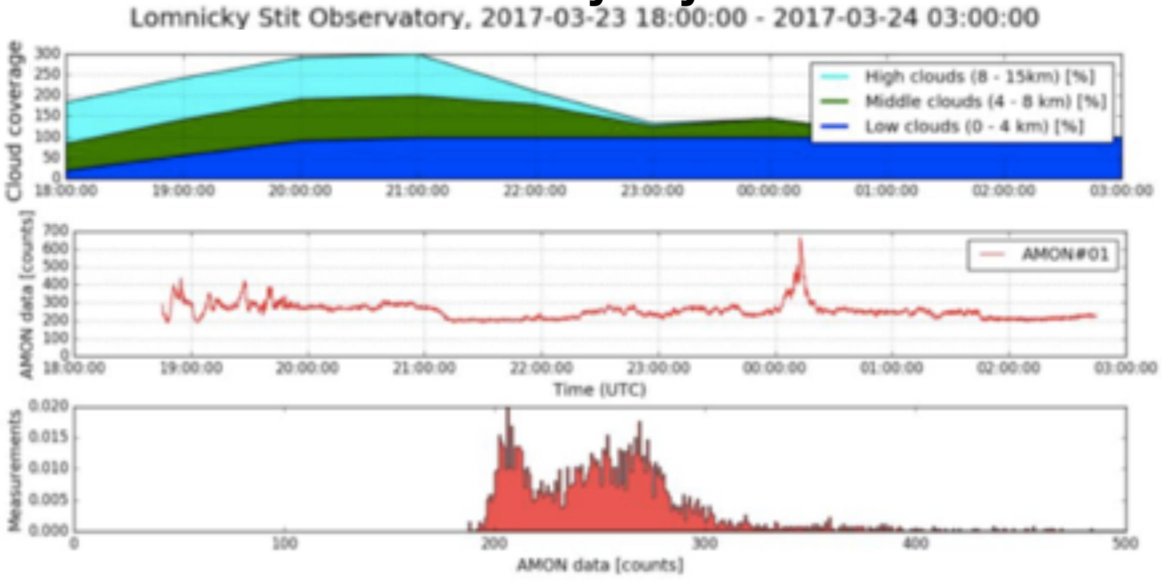


- Weather conditions (cloud coverage)

Clear sky



Cloudy sky



Global maps production and optimal observation points selection

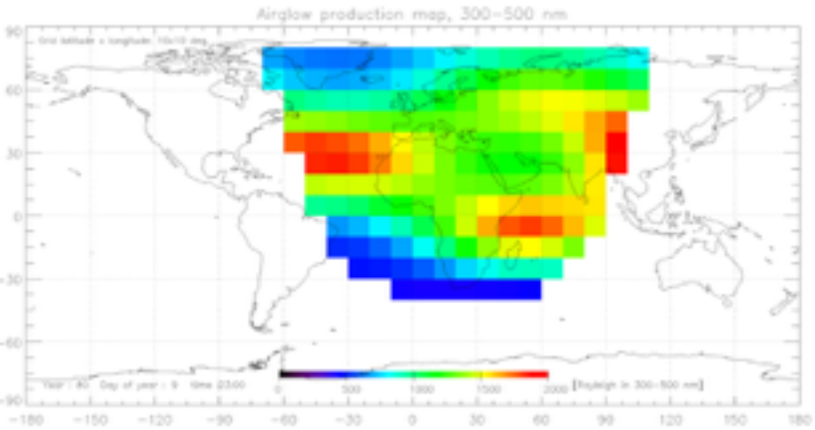


Figure 9. Airglow production at 9. January 1980, 23:00 UT.

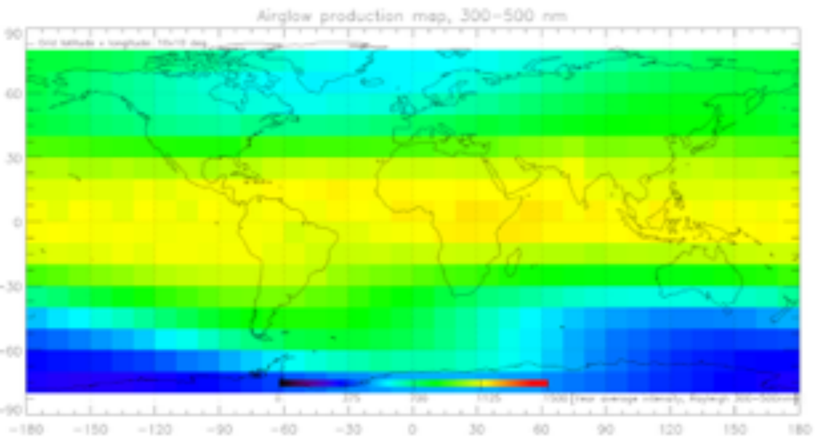


Figure 10. Airglow light production average for year 1980

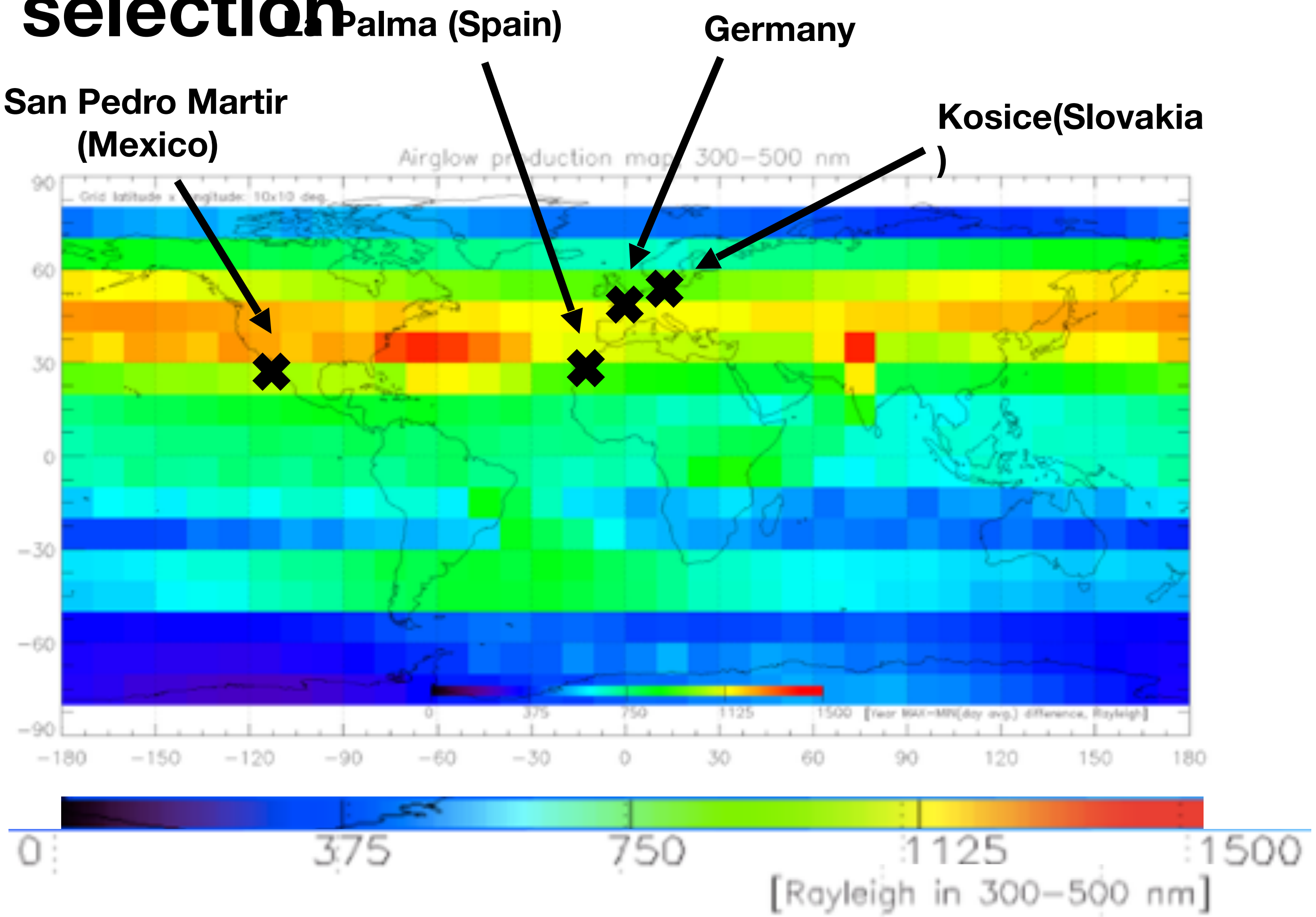
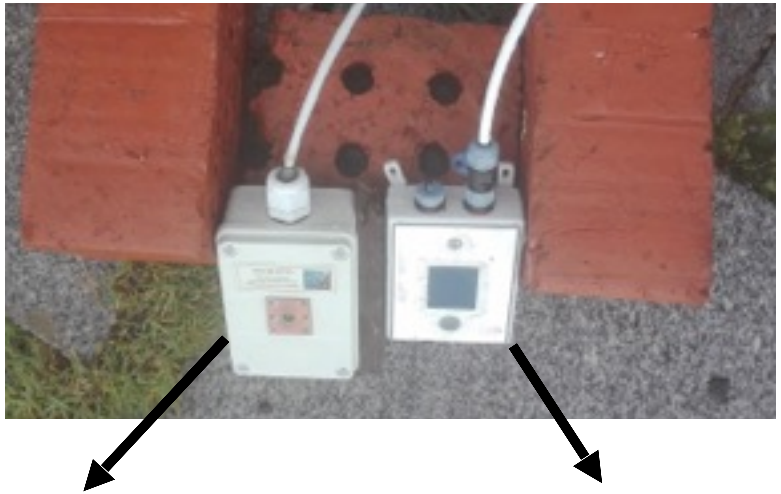


Figure 11. Seasonal variation of airglow light production in the year 1980.

Measurements in Lomnický štít (2634 m)



Cloud Watcher

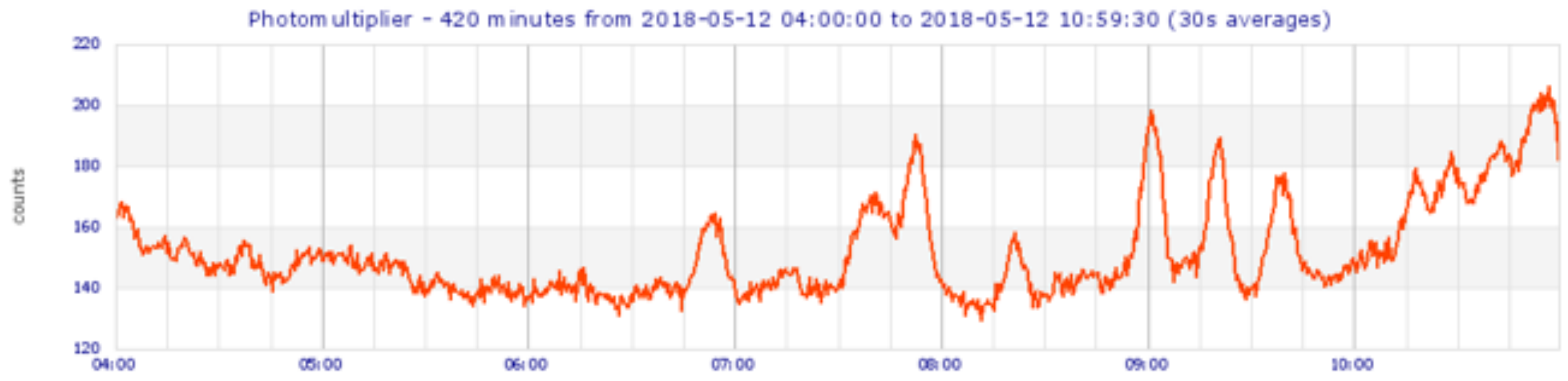
Figure13. Cloud Watcher

Cloud

Figure14. Photos made by Cloud Monitor

Figure15. Photos taken at the Lomnický štít Observatory

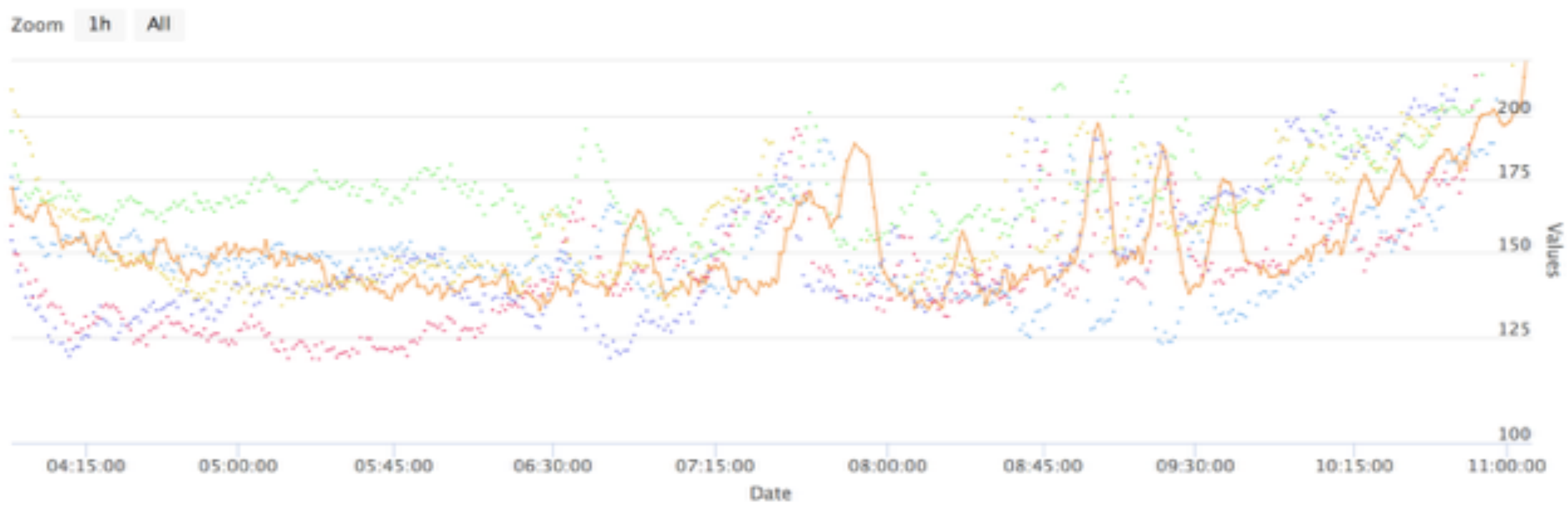
From the 12/05 to the 18 /05, Mexico



'Space physics database centre'

12/05/2018

04:00 – 11:00

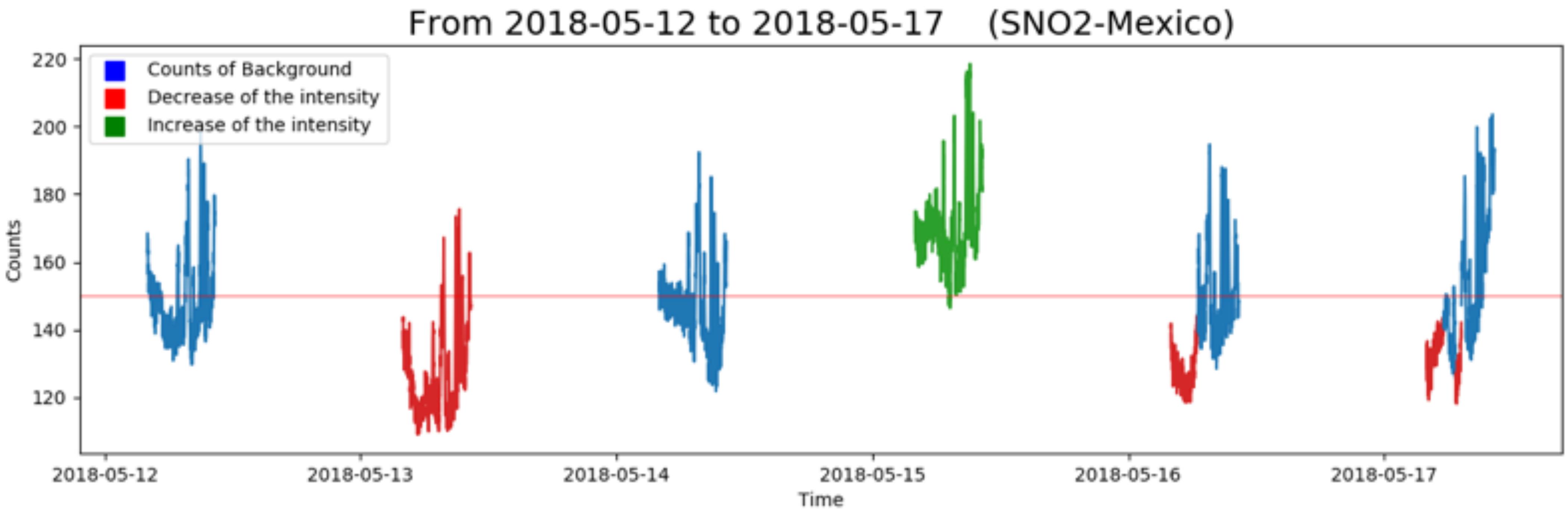


'Amon data visualizer'.

Comparing nights from 7 /05/2018 to 12/05/2018

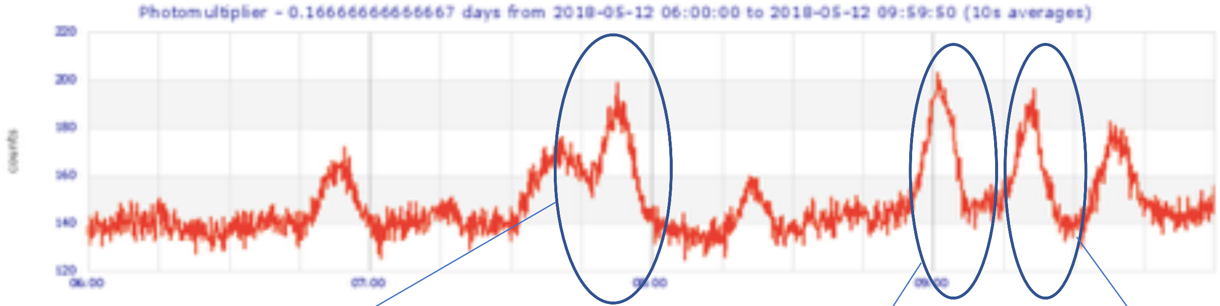
04:00 – 11:00

- Verifying for each night: Moon illumination, Moonrise time and Moonset time, Pressure, Temperature, Humidity, Presence of clouds or other metheorogical condictions, Geomagnetic data, Number of counts/s
- Writing codes on python: plot of the night counts
- “Jumping nights” → nights with decrease/increase of counts or with irregular trends

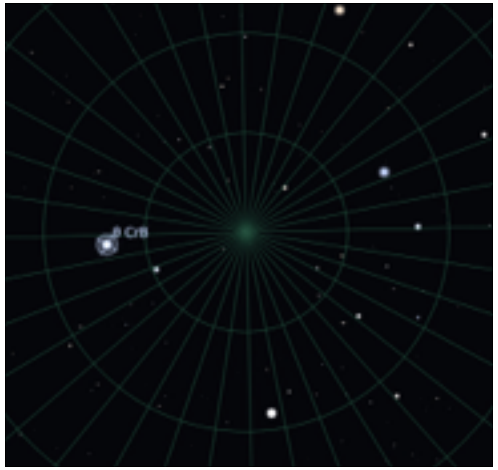


Identifying stars with “Stellarium”

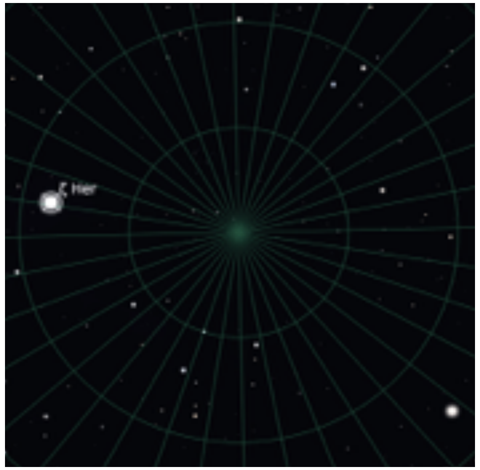
- Stellarium is a free open source. It shows a realistic sky in 3D. It is being used in planetarium projectors. Just set your coordinates.
- The coordinates of “San Pedro Martir Observatory”, Mexico are: **31°02'39.3"N 115°27'53.4"W**



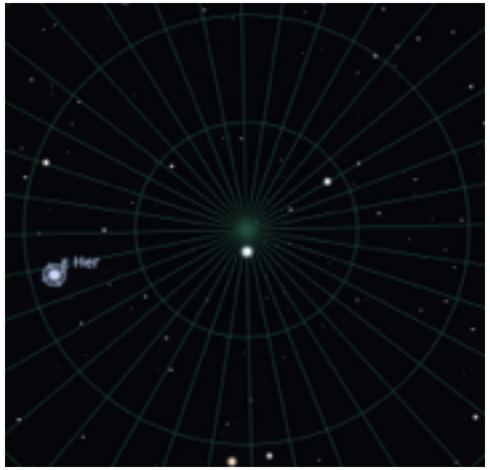
Theta Coronae Borealis



Theta Herculis



Eta Herculis



Identifying stars with the Poisson filter

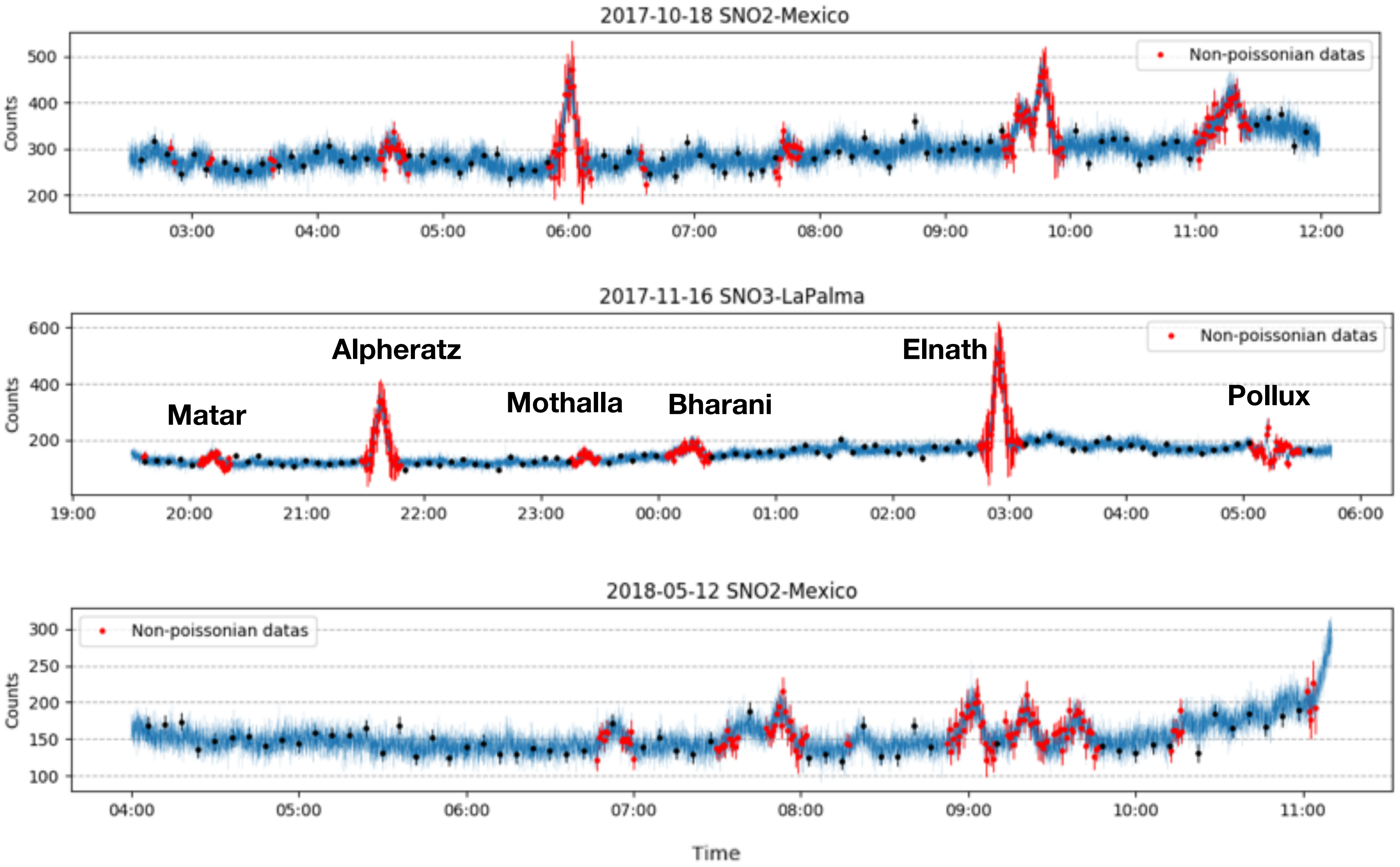
- How to identify fluctations of data → Poissonian distribution
- A python file takes all the AMON data and the times related to them
- A width of each time window has been chosen (12 minutes)
- Experimental deviation:

$$\sigma_{exp} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}}$$

- Theoric deviation:

$$\sigma_P = \sqrt{N}$$

- If $\sigma_{exp} < 1,2 \cdot \sigma_P$ poissonian distribution
- If $\sigma_{exp} > 1,2 \cdot \sigma_P$ non-poissonian distribution


2017-10-18 SNO2-Mexico
Non-poissonian datas
Counts
500
400
300
200
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
2017-11-16 SNO3-LaPalma
Non-poissonian datas
Counts
600
400
200
Matar
Alpheratz
Mothalla
Bharani
Elnath
Pollux
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
2018-05-12 SNO2-Mexico
Non-poissonian datas
Counts
300
250
200
150
100
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
Time

Starlight contamination in Amon measurements

- The presence of starlight and zodiacal light need to be taken into account as contamination to the absolute value of airglow intensity

➢ **Magnitude of stars**

Apparent magnitude: $m = -2{,}5 \cdot \log(l) + \text{cost}$

Absolute magnitude: $M = -2{,}5 \cdot \log(L) + \text{cost}$

$$l \propto \frac{1}{d^2} \;,\; L \propto \frac{1}{d_0^2} \quad,\; d_0 = 10 \text{ pc}$$

➢ **Equatorial coordinates system**

- Independent of the observer's location and the time of the observation
- Projection of the latitude and longitude coordinate system we use here on Earth, onto the celestial sphere

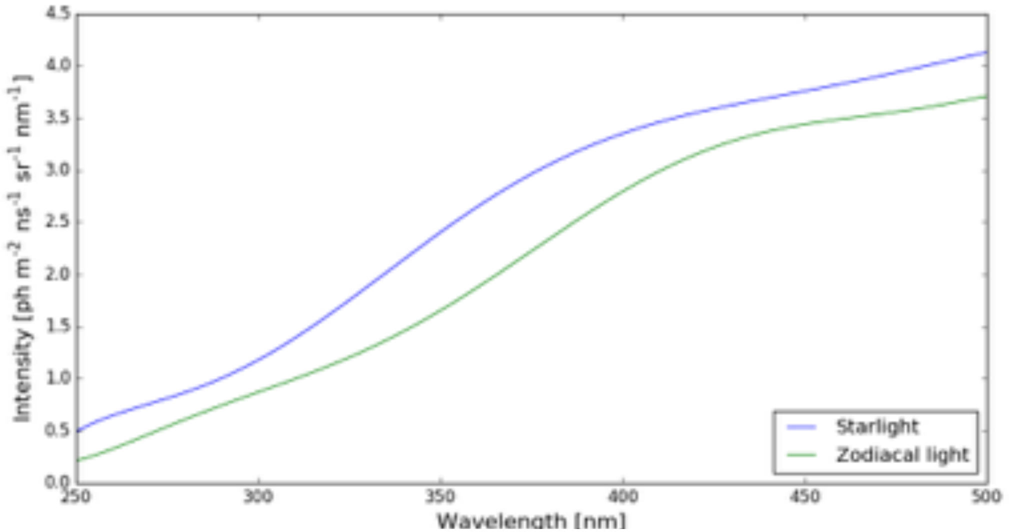


Figure 16. Spectrum at the Top of Atmosphere.

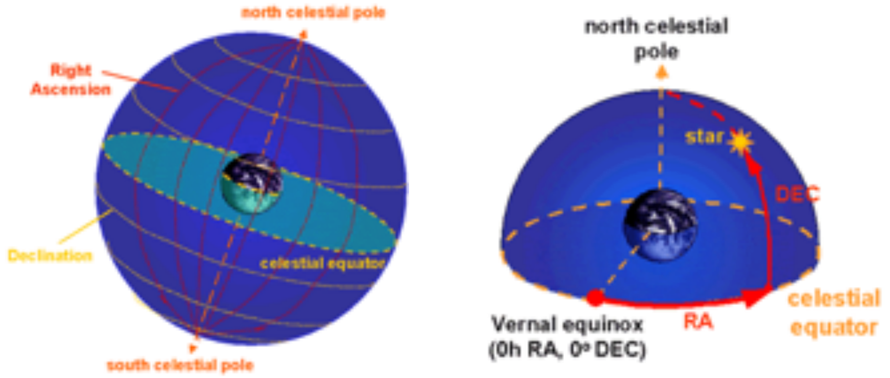


Figure 17. Equatorial coordinates system

Data source:

“Tycho-2 Catalogue ”

- 2,5 million stars with
- positions, proper motions, B_T and V_T magnitudes
- <u>It doesn’t include the brightest stars</u> (we will verify later the presence of 3 stars that we are going to analyze)

Assumptions:

A) We assume that AMON field of view is 1 sq degree (to be more precise we should re-evaluate Sky Map using the exact AMON FoV)

B) We assume that we could compare star light in counts from AMON measurements with luminosity from magnitudes from public source

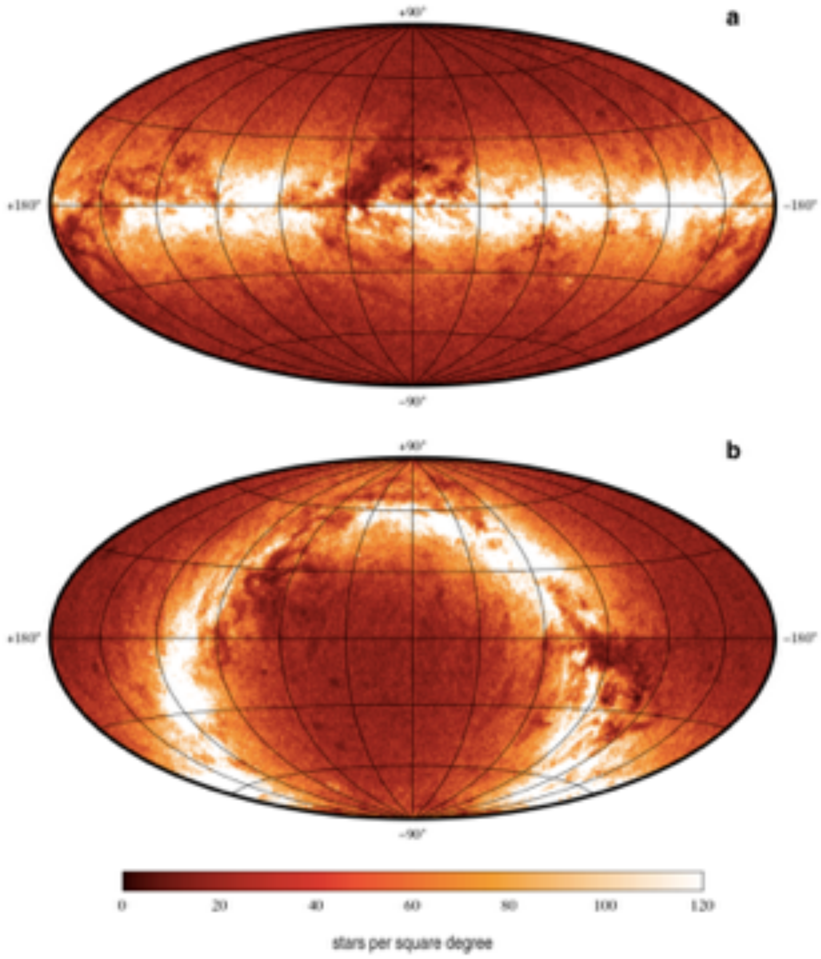


Figure 18. The density of Tycho-2 stars on the sky shown in galactic coordinates (panel a) and in equatorial coordinates (panel b)

- Tycho 2 catalogue was used to create a sky map (resolution 1 square degree ~FoV of AMON)
- The position of Amon in considered: Observatorio Astronómico Nacional San Pedro

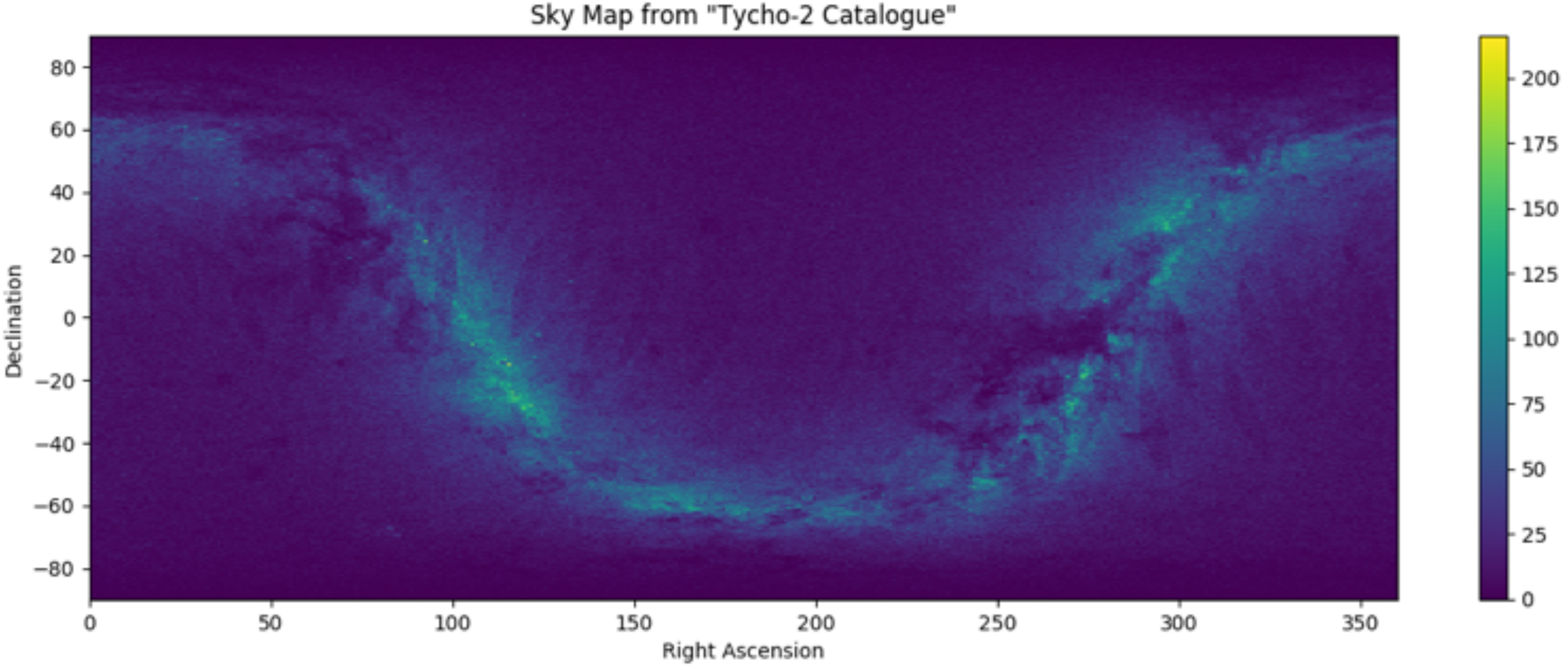
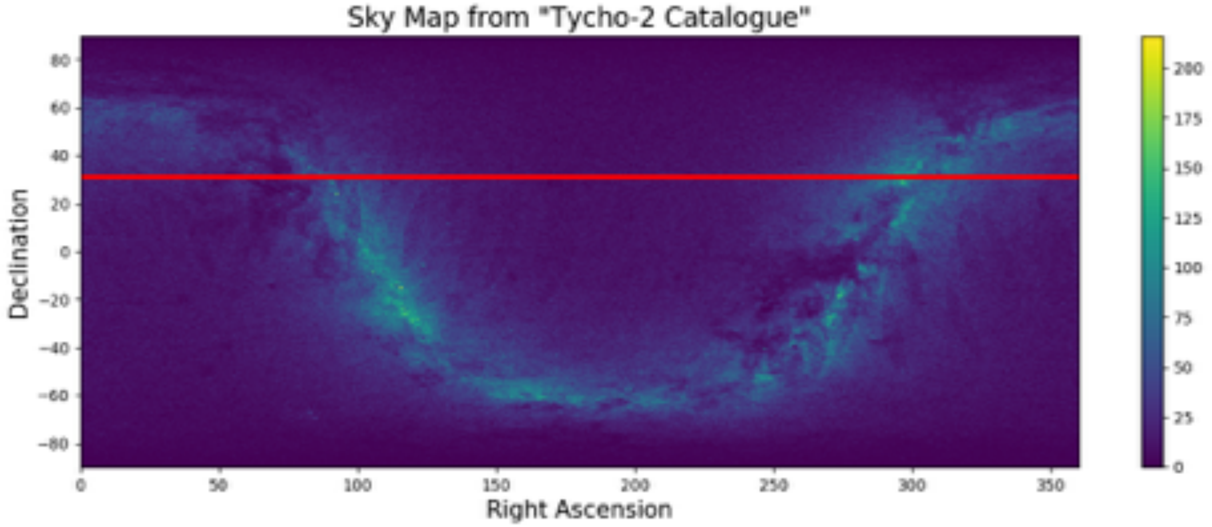


Figure 19. Density of stars in 1 square degree pixels evaluated from Tycho 2 catalogue.

- The red line shows the field of view of AMON from Mexico. Luminosities were summed to 1 square degree map pixels. The plot shows the luminosities from the field of view of AMON in Mexic



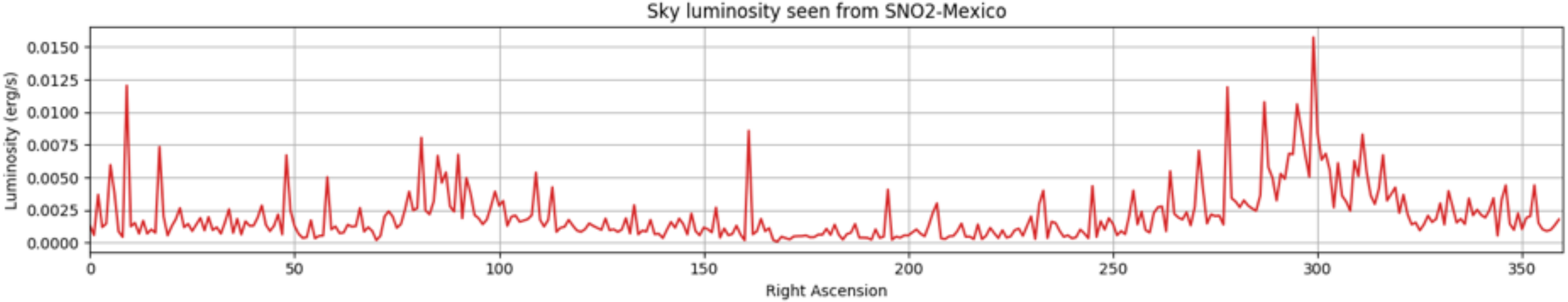
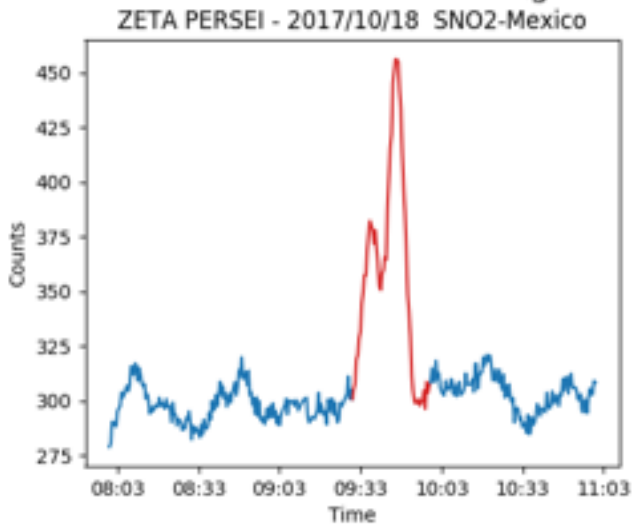


Figure 20. Integrated star light from zenith position in 1 square degree pixel in Mexico.

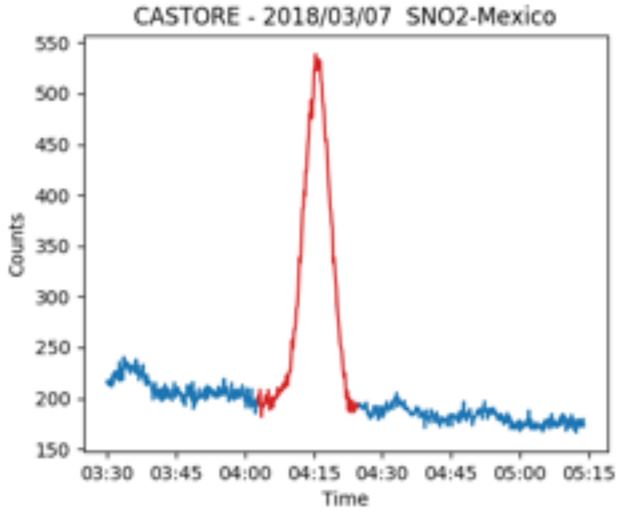
Conversion of units from Figure 3. to Amon counts:

- Clear peaks from stars was identified in AMON measurements (Alpheraz, Zeta Persei and Castore);
- High of peaks in AMON measurements was taken from measurements from few nights.

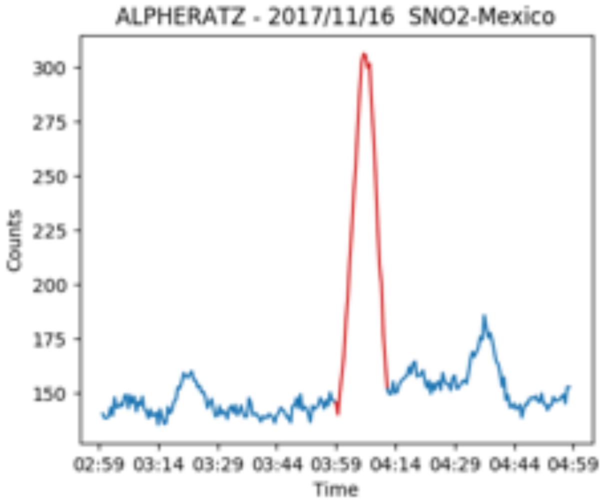
$$I_{ZetaPersei} \cong 153 \frac{counts}{s}$$



$$I_{Castore} \cong 283 \frac{counts}{s}$$

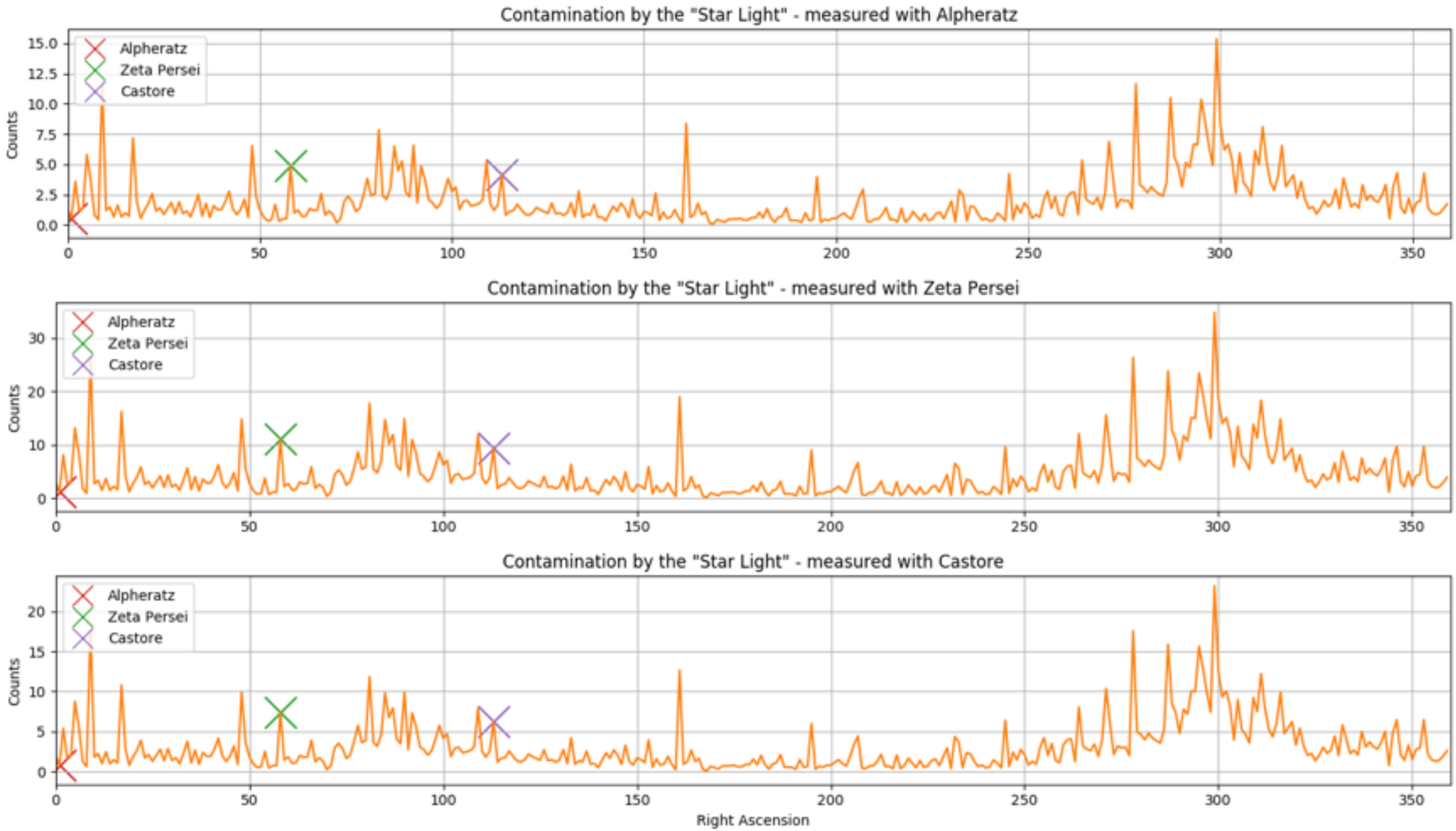


$$I_{Alpheratz} \cong 157 \frac{counts}{s}$$

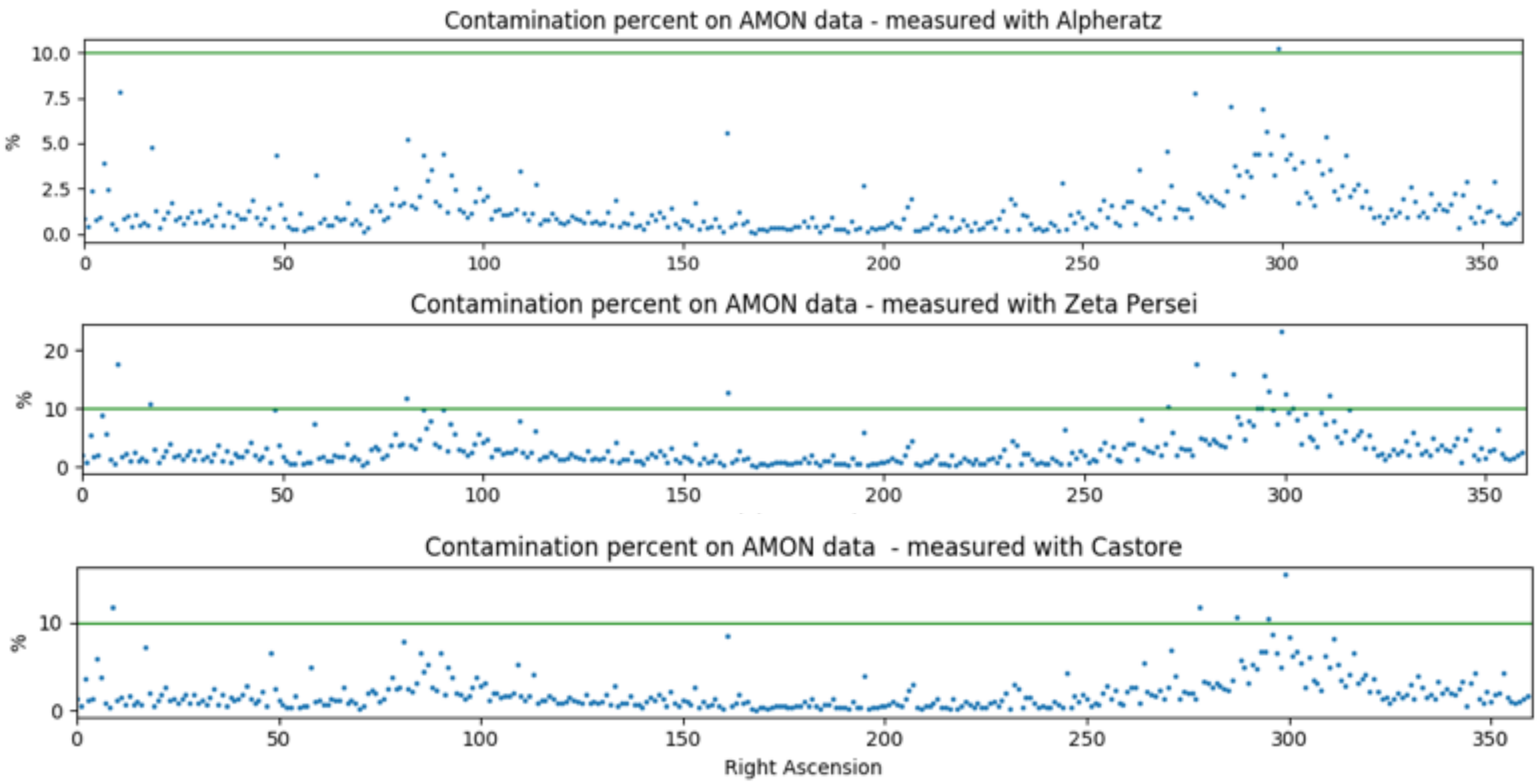


- Factor A was evaluated for every star, and it was used to convert luminosity from Sky Map to AMON counts :

$$A_{Alpheratz} = \frac{F_{Alpheratz}}{I_{Alpheratz}} \qquad I_{Sky\ Map,Alpheratz} = \frac{F_{SkyMap}}{A_{Alpheratz}}$$


Contamination by the "Star Light" - measured with Alpheratz
Alpheratz
Zeta Persei
Castore
Counts
Contamination by the "Star Light" - measured with Zeta Persei
Alpheratz
Zeta Persei
Castore
Counts
Contamination by the "Star Light" - measured with Castore
Alpheratz
Zeta Persei
Castore
Counts
Right Ascension

Percentual of contamination for 150 counts



Future developments

Prove of validity for the assumption B).

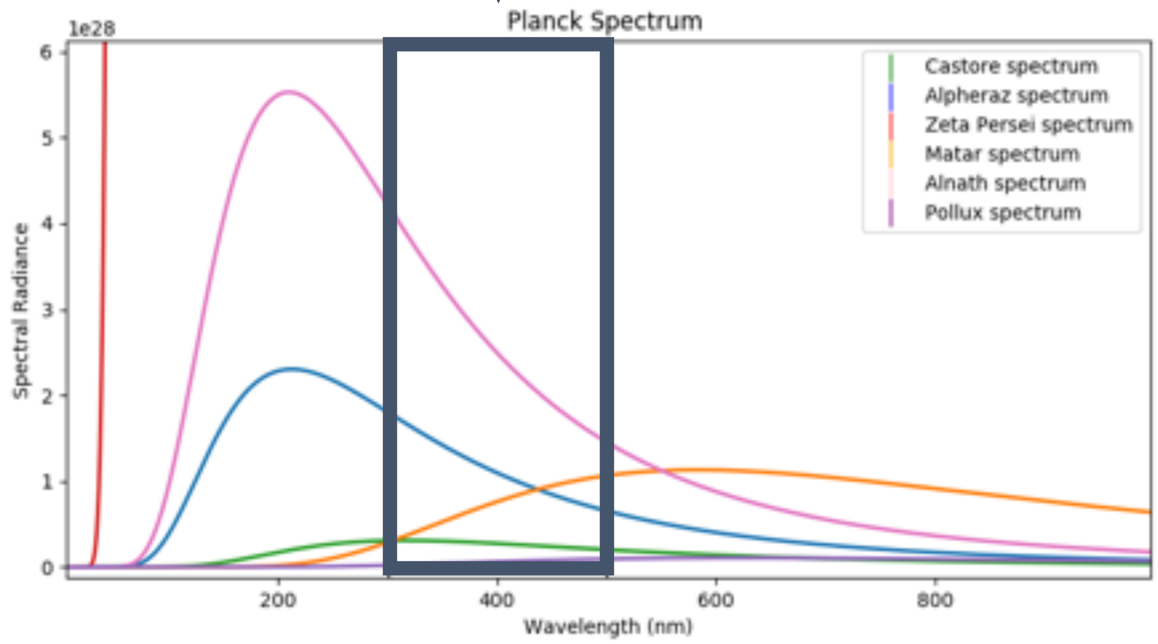
Stars luminosities ratios evaluated from:

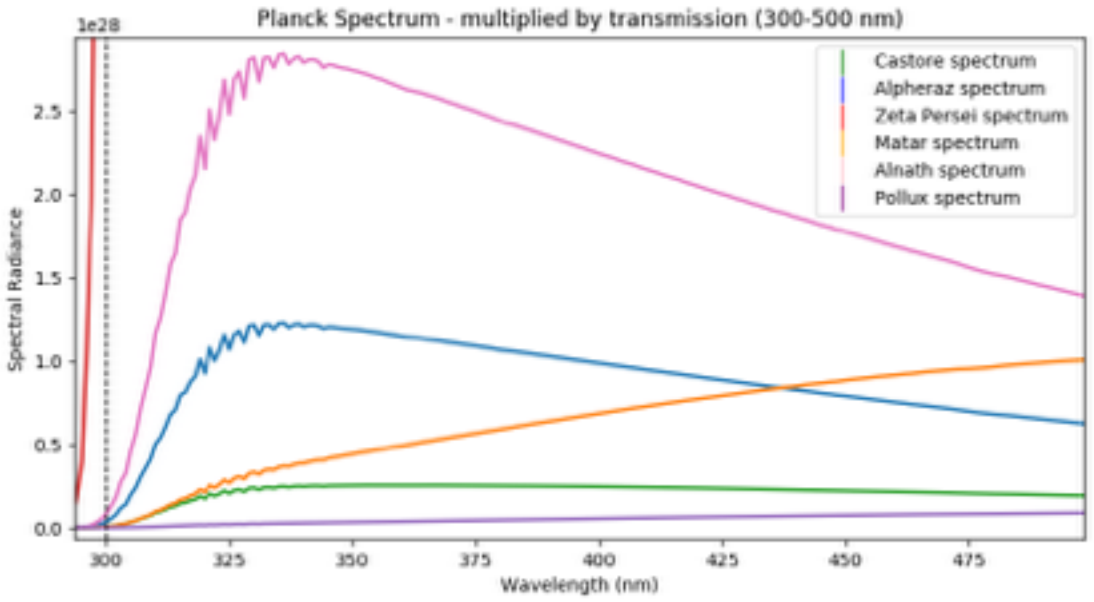
- Apparent magnitudes from public sources → $\mathbf{l_{magn} = 10^{-\frac{magnitude}{2,5}}}$
- AMON measurements → $\mathbf{l_{peak}}$ **= high of peaks**
- model of light of single stars → $\mathbf{l_{spectrum} = \frac{B_\lambda(\lambda,T)}{d^2} \cdot \pi r^2}$

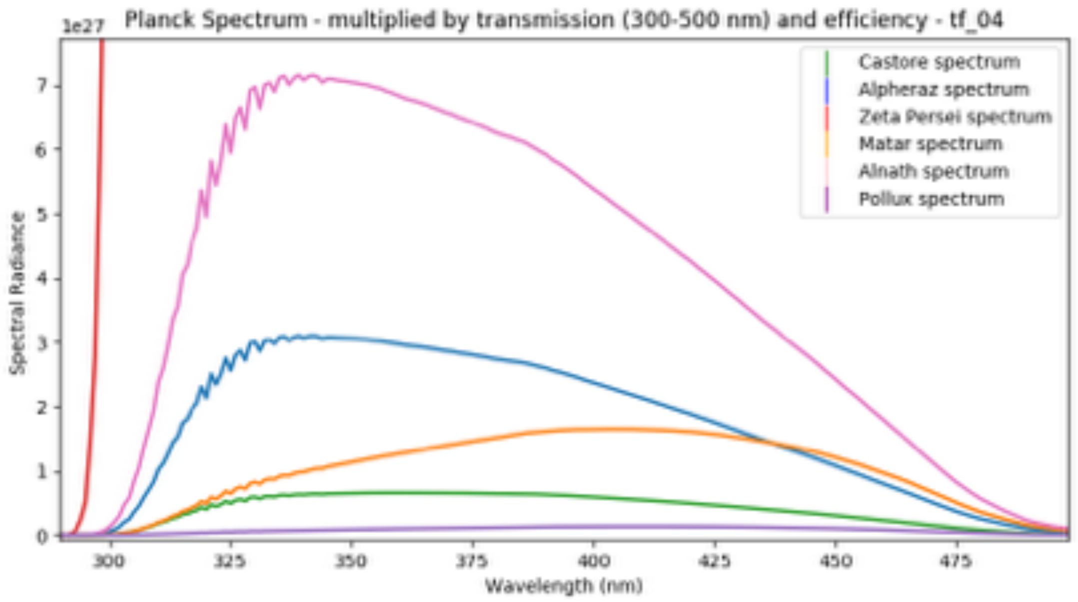
(from Planck spectrum $B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$ or from «ESO library» Spectrum)

Planck spectrum

- Capacity of transmission of the atmosphere
- QE of Amon and BG3 filter

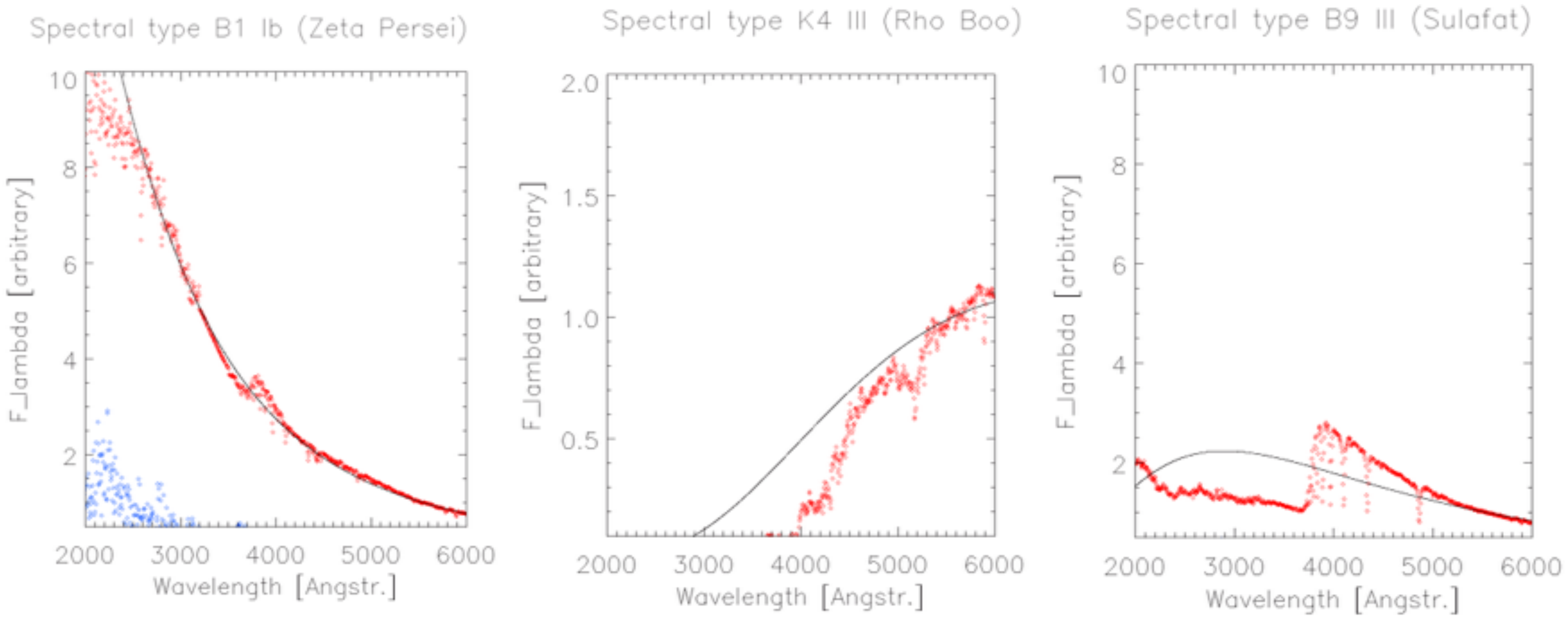






ESO library

Stars spectrum differs from Black Body spectrum → ESO library



Conclusions

- We have confirmed the operation of the ”Poisson filter", which works for the detection of stellar peaks, but not for detecting clouds.

- With the 2 assumptions, **we could conclude that contamination of star light in AMON measurements is less than 10%** (Comparing with measurements of AMON in Mexico ~ 150 counts/s), when AMON doesn’t observe directly bright star and Milky Way.

Thank you for your attention,

and I would more specifically thank the coordinator Prof. Mario Bertaina, the advisor Dr. Pavol Bobík and Simon Mackovjak for the assistance during my traineeship in Kosice.

Elisabetta Medina